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CASE STUDY

Sustainability assessment for multi-activity coastal areas using an integrated hierarchical decision-making framework

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ABSTRACT

BACKGROUND AND OBJECTIVES: Sustainability assessments of multi-activity coastal areas generally evaluate each utilization activity independently, leaving interdependencies unaccommodated and risking biased contribution estimates under conventional hierarchical weighting. This constraint carries profound implications for settings where anthropogenic activities vie for finite ecological space, most notably within tropical coastal socio-ecological systems in developing countries. The study objectives were to develop an activity-based sustainability assessment framework integrating hierarchical and network-based multi-criteria weighting to estimate the relative contribution of three activities: small-scale capture fisheries, vannamei shrimp ponds, and coastal tourism, in the coastal area of Pariaman City, Indonesia.

METHODS: Assessments covered 36 indicators across four sustainability dimensions: ecological, social, economic, and governance, with a 17-node interdependence network built from 14 indicators showing cross-activity dependencies through shared resources and identified causal pathways. Hierarchical weights for individual activities were derived independently by fifteen experts across three sectoral panels. Additionally, network-based weighting to account for inter-activity interactions was performed by a subset of five cross-sectoral experts. All pairwise comparison matrices satisfied the predetermined consistency threshold. The resilience of the regional index to weighting uncertainty was tested through sensitivity analysis.

FINDINGS: Network-based weights ranked vannamei shrimp ponds above small-scale capture fisheries and coastal tourism, but far less dominantly than under hierarchical weighting, which treated ponds as an extreme outlier by ignoring their negative influence on shared water quality and spatial resources. With a near-uniform contribution value of 0.554 across all three activities, the regional index underscores that intervention prioritization requires integrating interdependent cross-activity contributions rather than relying exclusively on standalone activity assessments. The moderately sustainable category held consistently across sensitivity scenarios, although activity contribution order proved more sensitive to weighting uncertainty.

CONCLUSION: Accounting for interdependence corrects the hierarchical approach's over-estimation of vannamei shrimp ponds and reveals a greater contribution from small-scale capture fisheries and coastal tourism than independent estimates suggest. The sustainability contribution of a given activity cannot be reliably determined in isolation from cross-sectoral interdependencies, highlighting the primary utility of this framework as a decision-support mechanism for coastal management.

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88	7	8

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INTRODUCTION

Coastal areas support over 2.4 billion livelihoods but face intensifying environmental pressures (Newton *et al*., 2020). In tropical developing countries, fisheries, aquaculture, and tourism share spatial zones and ecological foundations (Berkes, 2017; FAO, 2022; Stacey *et al*., 2021). Assessments focused on individual activities fail to capture the cross-sectoral trade-offs generated by these spatial overlaps (Folke *et al*., 2016; Hossain *et al*., 2020). Activity expansion in shared ecological space creates direct cross-sector effects. Shrimp aquaculture has caused over 1 million hectares of mangrove loss in Indonesia since the 1970s (Arifanti *et al*., 2021; Richards and Friess, 2016; Widigdo *et al*., 2024). These mangroves serve as nursery grounds for small-scale fisheries, which support ~90% of Indonesian fishing households (Rahmat and Neilson, 2023; Sari *et al*., 2021; Stacey *et al*., 2021; Yuliana *et al*., 2026a; Yuliana *et al*., 2026b). Aquaculture effluent compromises aquatic environmental quality, impairing fisheries and tourism, whereas tourism expansion simultaneously engenders spatial competition for marine resource utilization (Ketaren *et al*., 2026; Silalahi *et al*., 2024). In Pariaman, West Sumatra, vannamei shrimp farming expanded rapidly, yet only 19% of 58 ponds held full legal status (Desrizal *et al*., 2025). Meanwhile, small-scale fisheries declined, and coastal tourism grew across provincial marine destinations (Zamzami *et al*., 2023). These interconnections complicate management. Policies that benefit one sector may harm others sharing the same space. Consequently, Pariaman serves as an empirically representative case for integrated sustainability assessment. Multi-criteria evaluations in tropical coastal regions predominantly employ the analytic hierarchy process (AHP), a methodology prized for its transparent hierarchical framework (Cabrera and Lee, 2022). However, AHP assumes criterion independence. Evidence shows this systematically underestimates governance's role in coastal sustainability (Cabrera and Lee, 2022). Research modelling interdependence through analytic network process (ANP) demonstrates that priority rankings can shift significantly compared to independent approaches (Tuyen, 2024). Empirical Empirical findings further demonstrate that trade-offs are predominantly driven by spatial overlap among activity zones rather than intrinsic individual characteristics (Kurniawan *et al*., 2023), thereby exposing a fundamental limitation of conventional hierarchical methodologies. The independence assumption impedes representation of feedback relationships. This leaves inter-activity linkages unaddressed (Daimi and Rebai, 2023; Jorge-García and Estruch-Guitart, 2022). AHP remains appropriate for assessments with simple hierarchical structures, such as coastal-use suitability (Pourebrahim *et al*., 2010; Tian *et al*., 2013). However, when elements have reciprocal relationships that a one-way structure cannot represent, ANP is more suitable (Navarro *et al*., 2022). This study evaluates an environmental context wherein small-scale capture fisheries, intensive *vannamei* shrimp ponds, and coastal tourism sectors concurrently vie for shared ecological resources and space. Four sustainability dimensions (ecological, social, economic, and governance) mutually influence each activity. This interdependence necessitates AHP-ANP integration, not because ANP is inherently superior, but because the problem's characteristics demand it. AHP offers hierarchical clarity for weighting dimensions and indicators within each activity. ANP models dependency networks across activities (Sánchez-Garrido *et al*., 2022; Ziemba, 2019). Despite their utility, comprehensive methodologies coupling the AHP-ANP for concurrent multi-activity assessments in individual coastal areas are notably limited, especially within tropical coastal regions in developing countries (Chuang *et al*., 2018; Daimi and Rebai, 2023). Conventional assessments predominantly quantify sustainability contributions on a per-activity basis, presupposing an absence of cross-sectoral interdependencies (Kadoić *et al*., 2017; Saaty, 2008). This presumption is structurally unsound in multi-activity coastal regions. For example, shrimp

farming degrades water quality that supports fisheries productivity and tourism appeal. Unregulated pond expansion generates spatial conflicts. Governance failures propagate across activities through shared regulatory frameworks (Boyd *et al*., 2020; Ofori *et al*., 2023). These dynamics bias priorities toward sectorally dominant activities. They obscure reciprocal influences and undermine management effectiveness. The extent to which cross-sectoral interdependence shapes sustainability priorities remains empirically unverified. This knowledge gap necessitates a holistic assessment framework capable of concurrently evaluating the contributions of coastal activities. This study extends existing AHP-ANP methodologies through three primary contributions. First, by employing utilization activities instead of administrative sectors as the unit of analysis, the framework facilitates the estimation of both intrinsic sustainability (AHP) and systemic influence (ANP) for identical analytical entities. Second, the ANP network uses only indicators representing shared resources or theoretically identified causal pathways. This improves interpretability. Third, the composite index is decomposed to the indicator level. This identifies hub nodes driving divergence between AHP and ANP estimates. Collectively, these integrated features set the current framework apart from prior implementations in the literature. This study aims to develop and implement an activity-based sustainability assessment framework for the coastal area of Pariaman, West Sumatra, Indonesia. It covers three concurrent activities: small-scale capture fisheries, vannamei shrimp farming, and coastal tourism. The framework integrates AHP-ANP to model interdependencies between activities explicitly. Fieldwork was conducted in 2024.

MATERIALS AND METHODS

Study area

The study was conducted in the coastal area of Pariaman, West Sumatra, Indonesia (approximately 0°24′00″ – 0°52′32″ S and 99°57′44″ – 100°25′14″ E), encompassing the coastal administrative areas of Padang Pariaman Regency and Pariaman City, as shown in Fig. 1. Field investigations were conducted across nine coastal sub-districts, a setting characterized by intensive spatial interactions among three core sectors: small-scale capture fisheries, vannamei shrimp aquaculture, and coastal tourism. Small-scale capture fisheries are characterized by a fleet dominated by vessels of ≤5 gross tonnage (GT) (1,346 units, comprising 1,338 outboard-motor vessels and 8 motorboats without engines), while 18 vessels of 10–30 GT were excluded from the small-scale fisheries scope. Vannamei shrimp aquaculture covers approximately 72.3 ha of active ponds, and coastal tourism receives more than 2.3 million visitors annually (BPS Pariaman City, 2025; BPS Padang Pariaman Regency, 2025). The region also experiences mangrove conversion pressures and documented spatial-use conflicts (Firdaus *et al*., 2021), providing a representative setting for examining sustainability in a multi-use tropical coastal system. The selection of these three sectors reflects the restricted nature of industrial development in the region, coupled with the socio-economic dependence of coastal populations on small-scale capture fisheries, vannamei shrimp aquaculture, and tourism-related enterprises. In contrast, agriculture-based livelihoods, particularly paddy farming, are concentrated farther inland and are therefore outside the coastal utilization area examined in this study (Firdaus *et al*., 2021; Stanford *et al*., 2014).

Research framework

This study uses a quantitative multi-criteria decision analysis (MCDA) design with seven sequential stages: 1) identification of initial indicators through a literature search of coastal sustainability assessments; 2) selection and validation of indicators with experts and field stakeholders until 36 final indicators are obtained; 3) field measurement of indicators and preparation of a Saaty-scale paired-comparison questionnaire; 4) expert panel completion of the

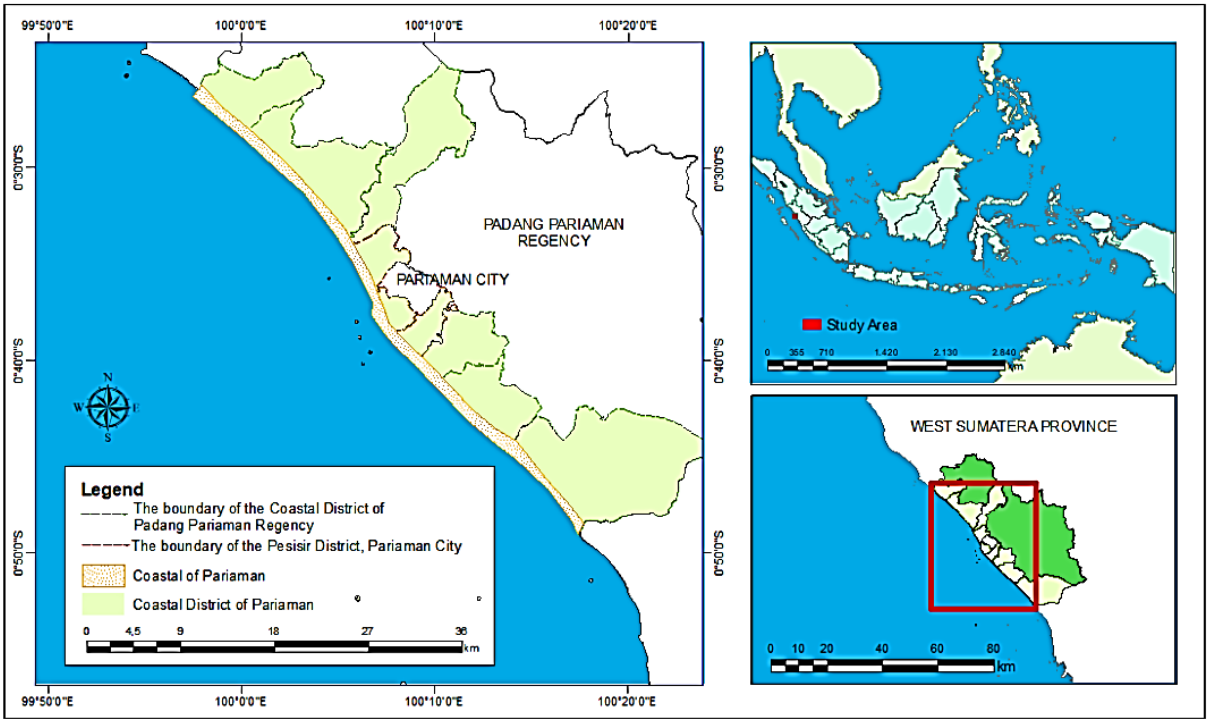

Fig. 1: Geographical location of the study área in the Pariaman coast, Indonesia

paired-comparison matrix; 5) calculation of dimension and indicator weights via the AHP; 6) construction of inter-activity interdependence networks and weight estimation via the ANP; and 7) evaluation of result robustness through sensitivity analysis, described sequentially in the following sub-sections. Utilization activities, rather than sectors or actors, serve as the primary unit of analysis in this study. These activities are evaluated across four dimensions: ecology (E), social (S), economic (K), and governance (G), using a total of 36 indicators. The proposed AHP-ANP integration is executed biennially—first, by applying AHP to determine the relative importance weights of dimensions and indicators per activity, and second, by employing ANP to estimate inter-activity contribution weights based on systemic dependencies within the network (Huang and Chen, 2024a; Kheybari *et al*., 2020; Saaty, 1996, 2004) as presented in Fig. 2.

Identification and validation of sustainability indicators

A review of coastal sustainability assessments was conducted to identify candidate indicators encompassing ecological, social, economic, and governance dimensions relevant to small-scale capture fisheries, vannamei shrimp ponds, and coastal tourism. A total of 36 indicators (4 dimensions × 3 indicators × 3 activities) were established to represent each sustainability dimension in a balanced manner per activity while keeping the expert-elicitation burden reasonable. The preliminary indicator set underwent a validation process involving regional experts and local stakeholders, including artisanal fishers, tourism representatives, pond management personnel, and community authorities, thereby verifying its contextual relevance to Pariaman's utilization context. The primary evidence offered for the indicator set's ability to represent sustainability comprehensively is this deliberate

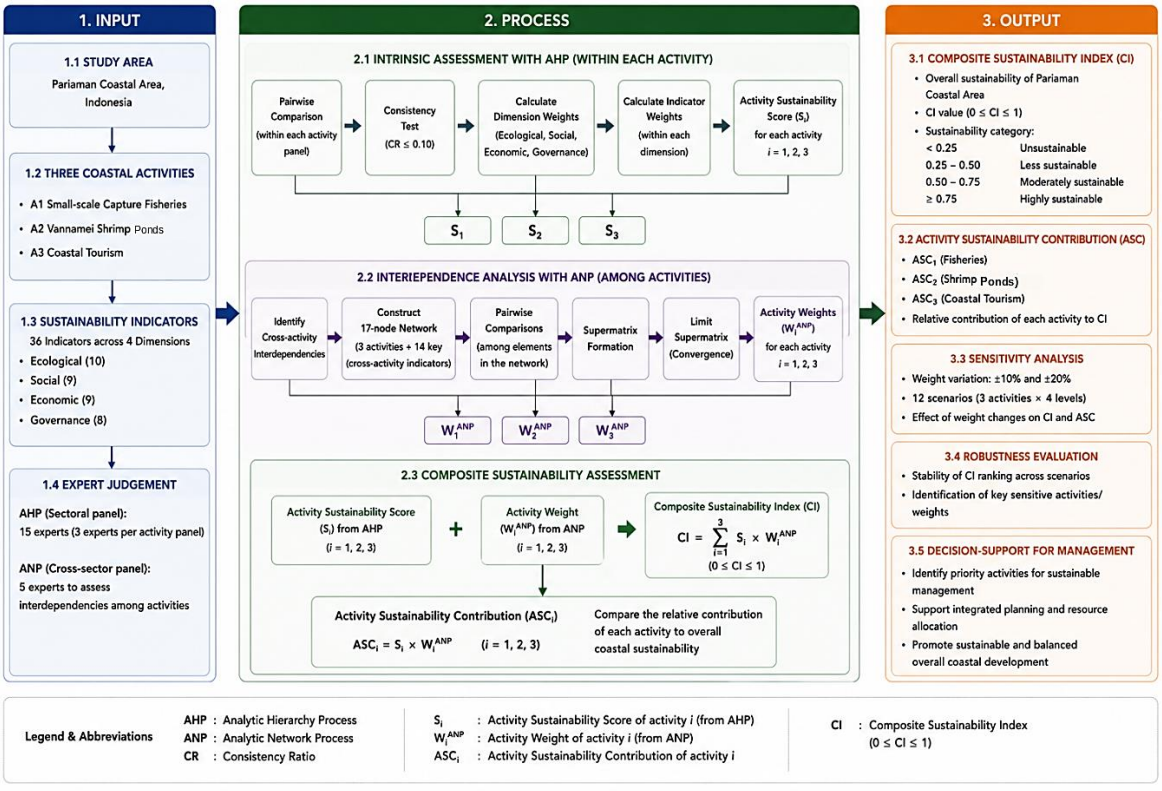

Fig. 2: Research framework for activity-based sustainability assessment (Integrating AHP and ANP to evaluate the sustainability contribution of coastal activities)

structural balance, three indicators allocated to each of the four dimensions (ecological, social, economic, and governance) within each activity, combined with expert and stakeholder validation of each candidate indicator's relevance; this constitutes a systematic, expert-informed basis for coverage rather than an independent statistical test of representativeness, and is acknowledged as such. The validated indicators were operationalized through field measurements and min–max normalization to a 0–1 scale, followed by AHP paired-comparison weighting to determine their relative importance.

Data collection

Secondary data were collected from agency documents and databases (West Sumatra Provincial Marine and Fisheries Agency, Padang Pariaman Regency Fisheries Office, BPS Pariaman City and Padang Pariaman Regency, Tourism and Culture Offices of Pariaman City and Padang Pariaman Regency) to identify and verify the 36 sustainability indicators and regional characteristics (fleet size, pond area, tourist numbers). Primary data were collected through two channels: (a) direct field measurements of the 36 indicators (September 2024-January 2025) across the Pariaman coastal zone, used to calculate indicator values (*Xi*) normalised to 0–1 via the Min-Max method; and (b) an expert-completed Saaty-scale paired-comparison questionnaire (Saaty, 2008), used for weighting indicators, dimensions, and activities and for modelling relationships between elements, secondary data and field measurements identify and verify regional conditions, while expert assessments weight and model inter-element relationships. In-situ data collection involved 65

sampling locations designated for artisanal fisheries, 50 for vannamei shrimp ponds, and 25 for coastal tourism operations. These points were allocated among the eight coastal sub-districts in proportion to the spatial extent of each activity. Water quality indicators, which exhibit the greatest temporal variability, were measured through three repeated observations during the study period to capture both short-term and seasonal variation. Because the remaining indicators demonstrated greater temporal stability, data collection for these variables was conducted once during the five-month monitoring period. All primary field observations were complete. Occasional incompleteness occurred in secondary data, where agency sources reported differing values for the same regional statistic. In these instances, the most credible and current source, typically the most recent official agency publication, was selected as the reference value. A purposive two-layer expert selection design was implemented. Fifteen experts were assigned to three sectoral panels (five per activity: small-scale capture fisheries, vannamei shrimp ponds, and coastal tourism), with each panel conducting paired comparisons exclusively within its sector. Furthermore, inter-activity comparisons and ANP network interdependencies were evaluated by a subgroup of five specialists possessing cross-sectoral expertise in coastal-marine spatial planning and tourism management. The selection criteria included: 1) a minimum of a Bachelor's degree, with most holding Bachelor's or Doctoral qualifications; 2) at least ten years of relevant professional experience (actual range: 10–20 years); 3) active engagement as academics, researchers, structural officials, or field practitioners; and 4) demonstrated contextual understanding of Pariaman City and Padang Pariaman Regency. The five-expert panel size follows the general AHP-ANP convention that assessment validity depends more on expert-domain competence than respondent count (Darko *et al*., 2019; Saaty, 2014; Srđević and Srđević, 2024); the diversity of backgrounds among academics, government officials, and field practitioners ensures sectoral panels handle within-activity relationships and cross-sectoral panels handle the inter-activity relationships requiring an integrative perspective. Their disciplinary backgrounds and experience are summarized in Table 1. The panel members—possessing between 10 and 24 years of expertise across academic, governmental, and practical sectors, were strategically assigned: sectoral panels managed intra-activity dynamics, while cross-sectoral specialists governed inter-activity interactions. Code legend: AC = Academic Expert; GS = Government Structural Expert; FP = Field Practitioner; ANP = expert panel selected specifically for the ANP (cross-sectoral) analysis.

Despite its smaller size relative to the 15-member sectoral panels, the five-member ANP cross-sectoral panel was purposely constituted to integrate all four dimensions of sustainability collectively, avoiding narrow representation of any isolated dimension (Table 1). ANP1's background in coastal resource management anchors the ecological and governance dimensions. ANP3's mandate in regional development planning, which within the Indonesian regency planning agency structure typically integrates economic and social welfare programming with spatial governance, anchors the economic, social, and governance dimensions. ANP4's role in marine and fisheries spatial planning anchors the ecological and governance dimensions. ANP5's experience in field-level integrated coastal management grounds the social dimension in community-level practice. ANP2's expertise in multi-criteria decision-support methodology is intentionally cross-dimensional, requiring the weighting procedure to synthesize all dimensions rather than privileging any individual aspect. This reflects cross-sectoral coastal governance roles, where administrative responsibilities may shift over time across institutions, jurisdictions, policy frameworks, and evolving environmental management priorities.

Table 1: Characteristics of the expert panels (AHP sectoral panels, n = 15; ANP cross-sectoral panel, n = 5). No expert held a direct financial or operational interest in the three utilization activities assessed

Code	Panel	Affiliation category	Area of expertise	Academic discipline	Experience (y)
AC1	AHP	Academic	Small-scale capture fisheries	Fisheries Resource Utilization	18
AC2	AHP	Academic	Aquaculture	Aquaculture	16
AC3	AHP	Academic	Coastal tourism	Tourism	14
AC4	AHP	Academic	Coastal zone management	Coastal Resources	20
AC5	AHP	Academic	Resource economics	Marine Economics	17
GS1	AHP	Government official	Development planning	Regional Planning	19
GS2	AHP	Government official	Coastal and marine spatial planning	Marine and Fisheries Affairs	18
GS3	AHP	Government official	Tourism	Public Administration	13
GS4	AHP	Government official	Environment	Environmental Engineering	15
GS5	AHP	Government official	Spatial planning	Regional Planning	21
FP1	AHP	Field practitioner	Capture fisherman	Small-Scale Capture Fisheries	24
FP2	AHP	Field practitioner	Shrimp farmer	Aquaculture	10
FP3	AHP	Field practitioner	Tourism operator	Tourism	15
FP4	AHP	Field practitioner	Fisheries extension officer	Fisheries Extension	20
FP5	AHP	Field practitioner	NGO / coastal community	Coastal Management	14
ANP1	ANP (cross-sectoral)	Academic	Coastal zone management (Ecological, Governance dimensions)	Coastal Resources	20
ANP2	ANP (cross-sectoral)	Academic	Decision support systems (cross-dimensional / methodological integration)	Industrial Management	18
ANP3	ANP (cross-sectoral)	Government official	Regional development planning (Economic, Social, Governance dimensions)	Regional Planning	19
ANP4	ANP (cross-sectoral)	Government official	Marine and fisheries affairs (Ecological, Governance dimensions)	Coastal and Marine Spatial Planning	18
ANP5	ANP (cross-sectoral)	Field practitioner	Integrated coastal management (Social, Ecological dimensions)	Coastal Management	24

Therefore, panel members were selected for broad and balanced coverage of relevant sustainability dimensions rather than narrowly defined or position-specific roles.

Development of the integrated AHP–ANP assessment framework

The proposed framework integrates AHP and ANP to accommodate two analytical needs: AHP derives priority weights from the hierarchical structure of sustainability indicators. In contrast, ANP models interdependence relationships between activities and indicators that a hierarchical structure cannot represent, combining indicator priorities with interdependence influence, as presented in Fig. 3.

AHP

The AHP model was organised as a four-level hierarchy: assessment goal, coastal activities, sustainability dimensions, and indicators (Fig. 4). This structure enabled the independent determination of each coastal activity's intrinsic sustainability score. Each activity, including small-scale capture fisheries, vannamei shrimp ponds, and coastal tourism, was evaluated using the same four dimensions: ecological, social, economic, and governance across 36 indicators. Pairwise comparisons were conducted only within each activity's hierarchy, consistent with the conventional AHP assumption of independence between activities. The AHP generates the dimension weight per activity (Wi_dimension) and

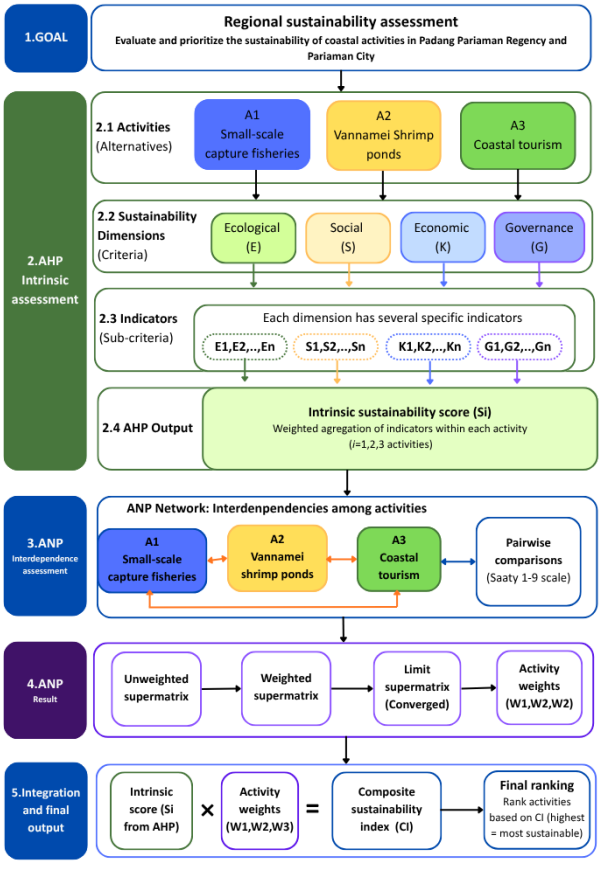

Fig. 3: Analytical structure of the integrated AHP–ANP assessment framework, illustrating how AHP-derived intrinsic sustainability scores (Si) and ANP-derived interdependence-based activity weights (Wi_ANP) are combined to obtain the regional composite index (CI) (A1 = Small-scale capture fisheries; A2 = Vannamei shrimp ponds; A3 = Coastal tourism)

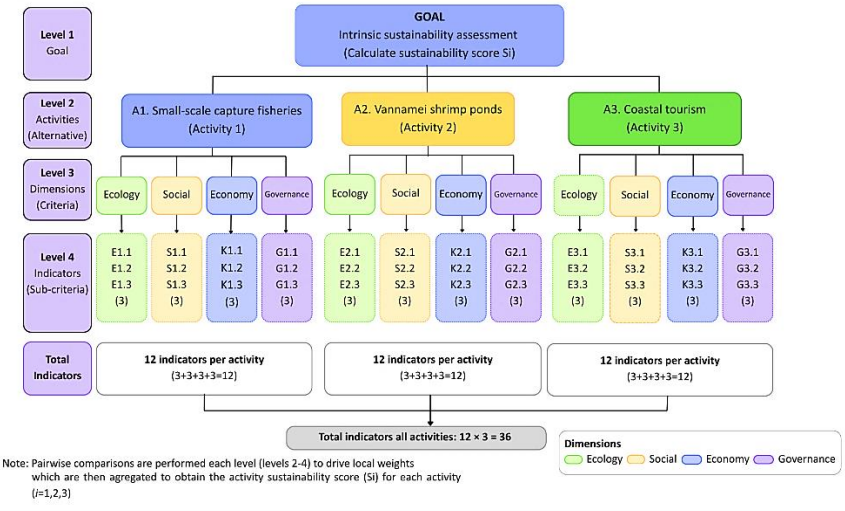

Fig. 4: AHP hierarchical structure for intrinsic sustainability assessment, showing the four-level pairwise-comparison structure (goal, activity, dimension, indicator) used to derive each activity's intrinsic sustainability score (Si) independently of the others (A1 = Small-scale capture fisheries; A2 = Vannamei shrimp ponds; A3 = Coastal tourism)

the indicator weight per dimension per activity (Wi_indicator) based on pairwise comparison assessments using the Saaty scale (1–9) (Saaty and Vargas, 2012). Fifteen experts, organised into three sectoral panels of five members each, conducted assessments exclusively within their respective sectors. The geometric mean of each panel's assessments was used to construct the aggregate matrix input, and consistency was verified using the Consistency Ratio (CR < 0.10). Rather than utilizing a dedicated consensus workshop, expert disagreements were reconciled by aggregating individual pairwise-comparison matrices via geometric means and applying a per-matrix CR screen, consistent with the standard AHP/ANP aggregation-of-individual-judgements (AIJ) framework. The sustainability score per activity (Si) is calculated using Eq. 1 (Saaty, 2008):

$$S_i = \sum(W_j \times \sum(W_k \times X_{ijk})) \quad (1)$$

Where: *Wj* is the weight of dimension *j*, *Wk* is the weight of indicator *k* in dimension j, and *Xijk* is the normalised value of indicator *k* of dimension *j* for activity *i*.

Development of the ANP network

Not all indicators enter the ANP network, since not all have a significant influence relationship on activities outside their own sector; most are sector-specific and already adequately represented through AHP weights within their respective activities; meaning only those forming inter-activity pathways of influence are modelled as ANP nodes. Nodes were selected based on two jointly applied criteria: 1) shared resources or conditions influenced by multiple activities, such as water quality affected by ponds but impacting fisheries and tourism; and 2) a theoretically identified causal pathway from one activity to another, supported by domain knowledge and coastal literature (for example, the water-quality pathway from pond effluent to fisheries and tourism performance cited above is documented in the shrimp-aquaculture wastewater management literature, e.g., by (Iber and Kasan, 2021). This methodological strategy is consistent with standard ANP protocols that emphasize theory- and expert-driven network architecture construction over automated filtering procedures (Saaty, 1996, 2004). Indicators present in more than one activity were not automatically designated as nodes. For example, Labour Absorption appears in both fisheries and ponds but satisfies neither criterion, as each absorbs labour with different skill sets and does not compete for the same resources. The 36 indicators underwent individual screening against two distinct benchmarks: shared environmental resources or conditions influenced by concurrent activities, and theoretically grounded inter-activity causal pathway. The research team, in consultation with the cross-sectoral expert panel, conducted qualitative screening based on expert knowledge and established ANP network-construction practices rather than numerical scoring. A notable limitation stems from its qualitative foundation. Without continuous scoring mechanisms, indicators near criterion thresholds are inherently more vulnerable to analyst or reviewer discretion. Excluding a borderline indicator could shift individual node weights; however, the overall network topology, defined by which activities are linked through shared resources, is expected to remain robust given the criteria's clear conceptual foundation. Application of these criteria to the 36 final indicators resulted in the network structure presented in Table 2.

ANP

The ANP comprised nine dependency blocks representing inter-cluster influences within the utilization network: 1) Ecology to activities; 2) Social to activities; 3) Economic to activities; 4) Governance to activities; 5) Activities to ecology; 6) Activities to social; 7) Activities to economic; 8) Activities to governance; and 9) Inner dependence of activities to activities. A paired-comparison matrix was constructed for each individual block based on evaluations provided by five subject-

Table 2: ANP network structure results from the implementation of screening criteria

Stages	Total
Final indicator (from AHP)	36
Indicator meets screening criteria (unique node)	14
Activity nodes added	+3
Total ANP network nodes	17

matter experts, generating 111 comparison pairs collected through a structured questionnaire. Consistency was evaluated for all 29 matrices; 26 matrices achieved a consistency ratio (CR) below 0.10, while the three 2×2 matrices were inherently consistent. The structure of the ANP network is illustrated in Fig. 5. The unweighted supermatrix (W) was constructed by populating each column with the priority vector derived from its respective comparison matrix. Subsequently, each column was normalised to sum to 1.0, resulting in the Weighted Supermatrix. The Supermatrix limit W^{∞} was determined through repeated powering (W^2, W^4, W^8, W^{16}) until convergence was achieved (Saaty, 1996, 2004; Saaty and Vargas, 2006). The final ANP weight (Wi_ANP) is the mean of the activity row at limit W^{16}, normalised so Σ*Wi*_ANP = 1.0, with all computations performed in Microsoft Excel using a specially developed supermatrix method.

Data analysis

Composite sustainability assessment

The AHP generates an intrinsic sustainability score (*Si*) for each activity based on its specific dimension and indicator weights. Although the standard AHP framework presumes strict independence among activities, this condition is not met in the Pariaman coastal zone, characterized by significant operational interactions via shared resources and spatial overlap. Consequently, the AHP-derived Si scores are not utilized as final outputs; rather, the composite area index incorporates ANP activity weights (Wi_ANP) to appropriately adjust each activity's relative contribution by capturing structural interdependencies through supermatrix convergence. As a result, the composite sustainability index (*CI*) reflects regional sustainability as an interconnected system rather than as a sum of independent achievements. In accordance with the standard weighted aggregation approach for composite indicators, the intrinsic sustainability score of each activity (*Si*) is combined with its relative activity weight (*Wi*) to calculate *CI*, ensuring that each activity's contribution is proportional to both its performance and its relative importance (Nardo *et al*., 2005):

$$CI = \sum(S_i \times W_i) \quad (2)$$

Where: *Si* is the sustainability score of activity *i* (from AHP) and Wi is the weight of activity *i* (both Wi_AHP and normalised Wi_ANP).

To compare the relative impacts of the three activities on overall regional sustainability—regardless of their intrinsic sustainability scores—each activity's contribution to the regional *CI* is quantified as the product of *Si* × *Wi*. Regional CI and activity contribution were calculated in two versions, using *Wi*_AHP and *Wi*_ANP, to compare the methodological implications of both weighting approaches. A decomposition follows directly from the weighted aggregation formulation, where *Si* × *Wi* represents activity *i*'s individual contribution to the composite index (CI). Sustainability levels are classified according to the four-tier system established by Rapfis (Kavanagh and Pitcher, 2004): unsustainable (<0.25), less sustainable (0.25-0.50), moderately sustainable (0.50-0.75), and highly sustainable (≥0.75). The same classification framework is utilized for both *Si* and *CI*. Because both frameworks share a conceptual 0–1 sustainability scale, the threshold

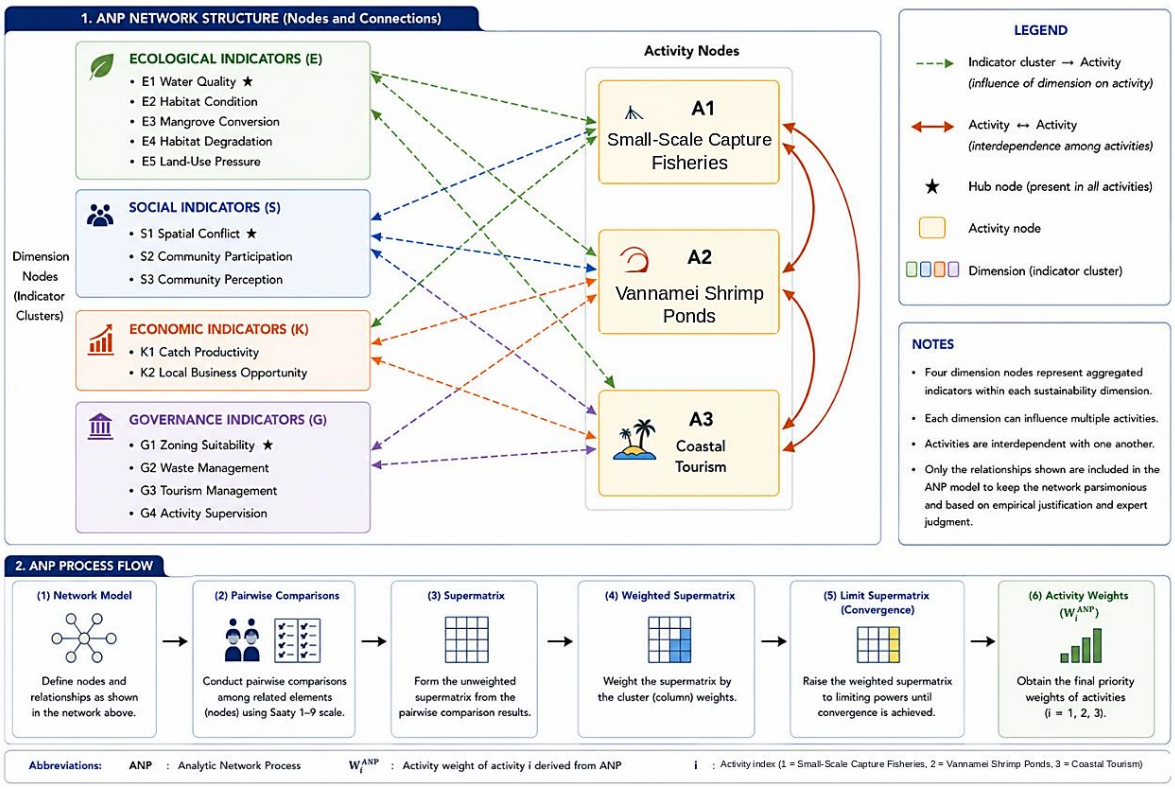

Fig. 5: ANP network structure for cross-activity interdependencies (Conceptual structure used to derive activity weights, W_i^{ANP}). A1 = Small-scale capture fisheries; A2 = Vannamei shrimp ponds; A3 = Coastal tourism

originally formulated for Rapfish multidimensional scaling (MDS) ordination is extended to the AHP-ANP composite index, with cross-method adaptation explicitly acknowledged as a study limitation. The transparency and simplicity principles for composite-index construction outlined by Nardo *et al*. (2005) underlie the choice of a discrete categorisation scheme in general, though the handbook does not explicitly prescribe specific thresholds.

Sensitivity analysis

To test the robustness of results against uncertainty in the estimated ANP weights, a one-at-a-time (OAT) sensitivity analysis varied each activity's weight (*Wi*_ANP) by ±10% and ±20% of baseline values, following variation magnitudes conventional in systematic reviews of MCDA sensitivity analyses (Więckowski and Sałabun, 2023). For target activity *i* that is varied by *d*, the new weight is calculated using Eq. 3 (Więckowski and Sałabun, 2023):

$$w_i' = w_i \times (1 + d) \quad (3)$$

The remaining weight $(1 - w_i')$ is then distributed to the other two activities (*j,k*) in proportion to their baseline weight ratio, using Eqs. 4 and 5 (Więckowski and Sałabun, 2023):

$$w_j' = w_j \times \frac{1 - w_i'}{w_j + w_k} \quad (4)$$

$$w_k' = w_k \times \frac{1 - w_i'}{w_j + w_k} \quad (5)$$

The redistribution follows a proportional normalization scheme commonly used in weighted sensitivity analysis, keeping total weight equal to one while preserving the relative

proportions among the remaining activities, using Eq. 6 (Więckowski and Sałabun, 2023):

$$wi' + wj' + wk' = wi' + (1 - wi') = 1 \qquad (6)$$

By construction, the total weight equals one in every scenario. A total of 12 scenarios (three activities × four variation levels) were recalculated to obtain the regional *CI* and activity priority ranking under each scenario. Rather than utilizing Monte Carlo or other probabilistic sensitivity procedures, an OAT design was implemented. This choice reflects the methodological constraints of relying on a five-expert panel for ANP weight estimation, which lacks the statistical power necessary to generate reliable probability distributions and avoids engendering a false sense of analytical precision. OAT sensitivity analysis instead produces directly interpretable, deterministic bounds on weight uncertainty appropriate to a small, purposively selected expert panel. Consequently, sensitivity analysis was restricted to uncertainty in the ANP activity weights (Wi-ANP). Potential variations from indicator measurements, environmental dynamics, socioeconomic constraints, and network topology were excluded from the simulation and acknowledged as limitations.

RESULTS AND DISCUSSION

Final Indicators and ANP nodes

The screening process, based on shared resources and causality pathways of interactivity, identified 14 of the 36 indicators as valid ANP nodes (Table 3). Three nodes (E1, S1, G1) serve as hubs, fulfilling both the screening criteria and connecting multiple activities. The 14 nodes are unevenly distributed across four dimensions: ecology (5), governance (4), social (3), and economic (2). This distribution suggests that inter-activity influence in Pariaman's coastal area is primarily governed by ecological mechanisms and the management of shared resources such as waters, land, and mangroves, as well as spatial management instruments. The pronounced sector-specificity of socioeconomic mechanisms corroborates standard ANP methodology, which dictates that influence pathways and structural interdependencies must be delineated before defining network architecture, avoiding the assumption of equivalent node weights (Kadoić *et al*., 2017). These nodes provide the foundation for the ANP network analysed in the following subsection.

AHP-derived dimension weights and intrinsic sustainability assessment

The AHP assessment produced two complementary outputs: (i) local weights reflecting experts' relative importance judgments for each sustainability dimension and indicator, and (ii) intrinsic sustainability scores reflecting each activity's observed field indicator performance. The sustainability profiles of the three activities spanning ecological, social, economic, and governance dimensions are delineated in Fig. 6, with comprehensive AHP-derived weights, indicator weights, and activity sustainability scores (*Si*) summarized in Tables 4a–4c. AHP yielded consistent matrices across all panels (CR = 0.001--0.092; mean 0.026; all < 0.10). Coastal tourism scored highest (*Si* = 0.695), followed by fisheries (0.529) and shrimp ponds (0.486). Ponds performed weakest in governance (Table 4a-c) (Saaty, 2008). All three activities fell within the moderate sustainability range (0.486–0.695). The tourism-fisheries gap (0.166) exceeded the fisheries-ponds gap (0.043), indicating ponds and fisheries perform similarly while tourism stands apart. AHP weights (*Wd*, *Wi*) reflect expert judgments of importance, whereas scores (*Xi, Si*) reflect field performance. Their product (*Wd* × *Wi* × *Xi*) identifies intervention priorities: high importance with low performance signals urgency, while high importance with high performance indicates strength. The ecological dimension dominated all activities, demonstrating maximal factor weights and optimal performance.

Table 3: Indicator nodes in the ANP network and cross-activity dependency justification

Code	Indicator	Sustainability dimension	Cross-activity dependency justification
E1	Water quality ★	Ecology	Shared resource: ponds pollute the waters → reduce fisheries productivity and tourist attractions. Critical hub nodes.
E2	Habitat conditions	Ecology	Tourism damages habitats → impacts fisheries. Two-way causality.
E3	Mangrove conversion	Ecology	Ponds convert mangroves → destroy nursery grounds and ecotourism bases.
E4	Habitat destruction	Ecology	Tourism and fisheries compete using the same habitat.
E5	Land use pressures	Ecology	Space competition: ponds, tourism, fishing settlements.
S1	Space conflict★	Social	Present in all three activities. Social hub nodes: formalising the pressures of space competition.
S2	Community participation	Social	Community-based tourism influences relevant participation for fisheries and ponds.
S3	Public perception	Social	The perception of coastal conditions is influenced by all three activities at once.
K1	Catch productivity	Economy	It is directly influenced by ecological quality (pond effect). Economic-ecological bridge.
K2	Local business opportunities	Economy	Tourism creates opportunities that can be taken advantage of by fishermen and farmers.
G1	Zoning suitability★	Governance	Present in all three activities. Governance hub nodes: the primary instrument for regulating inter-activity interactions.
G2	Waste management	Governance	Pond waste directly affects the quality of water → fisheries and tourism.
G3	Tourism area management	Governance	Tourism management affects the common ecological conditions.
G4	Activity supervision	Governance	Fisheries supervision affects the intensity of catches, which has an impact on tourist habitats.

★ = Hub node — comes as a cross-activity co-indicator

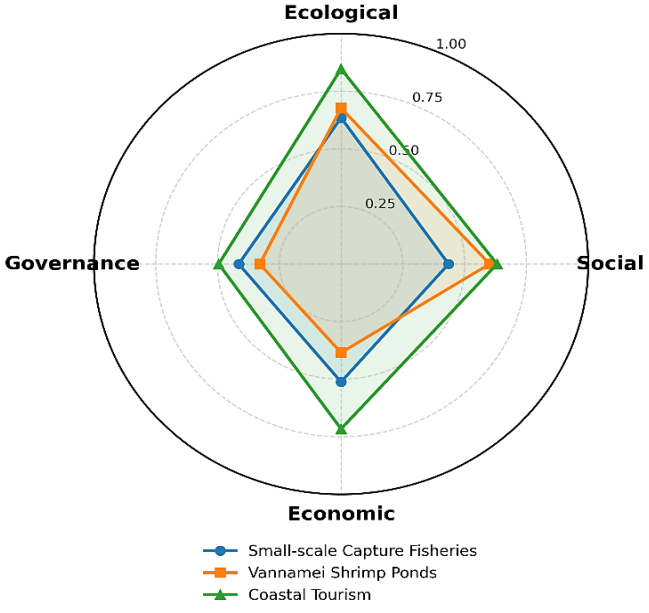

Fig. 6: Intrinsic sustainability profiles of the three coastal activities across the ecological, social, economic, and governance dimensions based on the AHP assessment

Tourism's top score (*Si* = 0.695) was driven by ecology (*Wd* = 0.473; performance = 0.829). Conversely, ponds' lowest score (0.486) stemmed not from ecology (score = 0.660) but from governance: high weight (*Wd* = 0.333) yet poor performance (0.313). This high-importance / low-performance combination makes governance, not ecology, the pond's main intervention priority.

Table 4a: Tiered weights, indicator weights, and sustainability scores (*Si*) for small-scale capture fisheries

Dimensions	Wd	Indicator	*Wi*	*Wd × Wi*	*Xi*	Contribution
		Pressure capture	0.161	0.0783	0.430	0.0337
Ecology	0.487	Quality of coastal waters	0.517	0.2519	0.850	0.2140
		Coastal habitat conditions	0.323	0.1572	0.339	0.0533
		Labor absorption	0.506	0.0685	0.401	0.0275
Social	0.135	Community dependency	0.393	0.0532	0.463	0.0246
		Utilization conflicts	0.101	0.0137	0.329	0.0045
		Fishermen's income	0.401	0.0835	0.377	0.0315
Economy	0.208	Capture productivity	0.408	0.0849	0.546	0.0464
		Stability of the fishery business	0.191	0.0398	0.637	0.0254
		Regulatory compliance	0.467	0.0790	0.386	0.0305
Governance	0.169	Activity monitoring	0.222	0.0375	0.345	0.0129
		Zoning suitability	0.311	0.0526	0.462	0.0243
Total	1.000			1.000		*Si* = 0.529

Table 4b: Tiered weights, indicator weights, and sustainability scores (*Si*) for vannamei shrimp ponds

Dimensions	Wd	Indicator	Wi	Wd × Wi	Xi	Contribution
		Mangrove conversion	0.172	0.0657	0.380	0.0250
Ecology	0.381	Pond water quality	0.632	0.2408	0.795	0.1914
		Land use pressures	0.196	0.0747	0.470	0.0351
		Labor absorption	0.418	0.0467	0.590	0.0275
Social	0.112	Land use conflicts	0.147	0.0164	0.662	0.0109
		Impact on society	0.435	0.0486	0.580	0.0282
		Pond productivity	0.292	0.0508	0.392	0.0199
Economy	0.174	Profit of the business	0.425	0.0740	0.362	0.0268
		Production stability	0.283	0.0494	0.352	0.0174
		Licensing compliance	0.248	0.0827	0.450	0.0372
Governance	0.333	Waste management	0.647	0.2156	0.235	0.0507
		Zoning suitability	0.104	0.0348	0.470	0.0163
Total	1.000			1.000		*Si* = 0.486

Table 4c: Tiered weights, indicator weights, and sustainability scores (*Si*) for coastal tourism

Dimensions	Wd	Indicator	*Wi*	*Wd × Wi*	*Xi*	Contribution
		Destruction of coastal habitats	0.176	0.0833	0.680	0.0566
Ecology	0.473	Tourism waste and waste	0.572	0.2708	0.800	0.2166
		Quality of coastal waters	0.252	0.1190	1.000	0.1190
		Community participation	0.533	0.0675	0.627	0.0423
Social	0.127	Public perception	0.373	0.0472	0.628	0.0297
		Space utilization conflicts	0.094	0.0119	0.450	0.0054
		Tourism revenue	0.257	0.0404	0.650	0.0262
Economy	0.157	Number of tourist visits	0.583	0.0916	0.634	0.0581
		Local business opportunities	0.160	0.0251	1.000	0.0251
		Management of tourist areas	0.146	0.0355	0.450	0.0160
Governance	0.243	Tourism facilities and regulations	0.624	0.1517	0.508	0.0771
		Zoning suitability	0.230	0.0559	0.404	0.0226
Total	1.000			1.000		Si = 0.695

Wd = dimension weights in the activity; *Wi* = the weight of the indicator in dimensions; *Wd × Wi* = global weight indicator; *Xi* = Min-Max normalised indicator value (range 0–1); Contribution = *Wd × Wi × Xi; Si* = activity composite sustainability score = Σ contribution.

A similar pattern occurs in tourism: governance is high-weighted (*Wd*=0.243, ranked 2nd) but its performance is far below ecology (0.476 vs 0.829), although still better than ponds in absolute terms. In contrast, capture fisheries demonstrate an intermediary profile characterized by a relatively equitable pressure gradient across governance (0.401) and social (0.418) indicators. At the indicator level, the importance-performance pattern remains consistent: the highest-weighted indicators within the ecology dimension are also the strongest performers. Specifically, coastal

water quality in fisheries (*Wi*=0.517, *Xi*=0.850) and pond water quality in ponds (*Wi*=0.632, *Xi*=0.795) represent both the most important and best-performing indicators in their respective dimensions. In contrast, waste management in ponds, which is the highest-weighted governance indicator (*Wi*=0.647) coupled with the lowest performance score (*Xi*=0.235), thereby highlighting it as the critical leverage point demanding immediate intervention in the comprehensive evaluation. First, AHP results indicate governance-not ecology- as the primary weakness for shrimp ponds (*Si* governance = 0.313), consistent with documented pond-waste threats to shared water quality (hub node E1) (Boyd *et al*., 2022; de Lacerda *et al*., 2021; Iber and Kasan, 2021; McSherry *et al*., 2023). Second, ecological stress in aquaculture is significant, as intensive aquaculture imposes a high ecological burden in tropical coastal areas (Akram *et al*., 2023; Ariadi *et al*., 2025; Boyd *et al*., 2022; Goldberg *et al*., 2020; Ottinger *et al*., 2022; Rizky *et al*., 2025). While this phenomenon is pertinent at the regional scale, within the context of Pariaman, ecological stress is predominantly channeled through governance deficits rather than direct ecological degradation of the ponds. Third, tourism-related environmental risk is a concern, as community-based tourism is generally susceptible to environmental degradation if not managed effectively (Boustead and Bhatta, 2021; Kakkar and Upadhyay, 2025; Reddy, 2018).

ANP weights

The ANP network is built from 17 nodes (14 indicators selected in Section 3.1 plus 3 activity nodes), organised in nine dependency blocks. Before interpreting the ANP weights, consistency of all paired-comparison matrices forming this network was first verified. All 29 ANP matrices were valid, with excellent consistency: 26 met CR < 0.10 (range 0.000–0.060, mean ≈ 0.014), while 3 matrices in the Economy→Activity block are 2×2, consistent by definition (Table 5). Absence of entries in the Economic→Pond block stems from the lack of direct relevance between the network's economic indicators and the model-specific shrimp pond, rather than implying a broader generalization concerning the economic profile of shrimp aquaculture beyond this framework. The final ANP weight, obtained from the supermatrix limit, is compared with the AHP weight in Table 6. Ponds showed the largest weight correction (Δ = −0.200; 0.588 to 0.388), while fisheries and tourism increased moderately (Δ = +0.103 and +0.097). The ranking (ponds > fisheries > tourism) remained stable, but relative magnitudes shifted---a pattern consistent with prior AHP-ANP comparisons (Jorge-García and Estruch-Guitart, 2022; Lin *et al*., 2024). By failing to account for negative mutual interactions, AHP disproportionately overestimates sectorally dominant activities (Kadoić *et al*., 2017; Saaty, 2006). In contrast, ANP corrects this bias, producing a balanced and proportional weight distribution. The implications for decision-making are substantial: AHP supports stringent restrictions on pond operations (weight 0.588), whereas ANP advocates for more balanced, integrated management, as reflected in the more proportional weights (0.388:0.360:0.252). This correction reflects the network structure, not a mathematical artefact. Three hub nodes link activities: water quality (E1), spatial conflicts (S1), and zoning suitability (G1). Ponds exert the greatest pressure on these hubs (via E1 and G1), explaining their largest weight reduction. Fisheries and tourism, as net recipients of hub-node impacts, gained relative weight. These hub nodes further validate the structural constraints of AHP, demonstrating that a purely hierarchical design fails to account for the interconnected network properties characteristic of shared indicators (Chen and Ren, 2017; Gonzalez-Urango *et al*., 2023; Huang and Chen, 2024b; Lin *et al*., 2024; Saaty, 1996; Ziemba, 2019). Rather than relying solely on the application of ANP, the principal contribution of this study resides in demonstrating how the inclusion of activity interdependencies shifts the evaluated sustainability profile of each

Table 5: Summary of the consistency ratio (CR) values of all ANP matrices

Dependency blocks	n Spouse	Matrix	CR Min	CR Max	Status
Ecology → Activity (E→A)	10 per activity	3	0.007	0.044	✓ Consistent
Social → Activities (S→A)	3 per activity	3	0.006	0.058	✓ Consistent
Economy → Activity (K→A)	1 per activity	2 *	0.000	0.000	✓ Consistent
Governance → Activities (T→A)	6 per activity	3	0.008	0.027	✓ Consistent
Ecology → Activities (A→E)	3 per E node	5	0.005	0.046	✓ Consistent
Social → Activities (A→S)	3 per node S	3	0.001	0.042	✓ Consistent
Economic → Activities (A→K)	3 per node K	2	0.001	0.028	✓ Consistent
Governance → Activities (A→T)	3 per node T	4	0.001	0.060	✓ Consistent
Inner dependence (A→A)	3	3	0.018	0.051	✓ Consistent

*Economic Block → Shrimp ponds = 0 (no relevant ANP economic node for shrimp ponds)

Table 6: Activity weight comparison: AHP vs normalised ANP

Activities	*Wi*_AHP	Rank AHP	*Wi*_ANP ternorm	Rank ANP	Δ (ANP−AHP)	n
Vannamei shrimp pond	0.588	1	0.388	1	−0.200*	5
Small-scale capture fisheries	0.257	2	0.360	2	+0.103*	5
Coastal tourism	0.155	3	0.252	3	+0.097*	5
Total	1.000	-	1.000	-	-	-

|Δ| ≥ 0.05 = methodologically substantial difference; n = number of experts; *CI and activity contribution*

Table 7: Composite index of regional sustainability: AHP vs ANP comparison

Activities	*Si*	*Wi*_AHP	*Si*×*Wi*_AHP	*Wi*_ANP Norm	*Si*×*Wi*_ANP	Δ
Small-scale capture fisheries	0.529	0.257	0.136	0.360	0.190	+0.054
Vannamei shrimp pond	0.486	0.588	0.286	0.388	0.189	−0.097
Coastal tourism	0.695	0.155	0.107	0.252	0.175	+0.068
CI Area	-	-	0.529	-	0.554	+0.025

sector. In contrast, the conventional AHP assumes strict independence across activities and thus obscures these coupled effects. While including interdependencies does not affect the priority order, it changes the relative magnitude of each activity's contribution, thereby providing a more proportionate foundation for decision-making than an independent hierarchical approach. Although AHP assesses each activity's intrinsic sustainability profile independently, the observed patterns indicate that several priority issues extend beyond individual activities due to shared environmental resources. These cross-activity relationships are explicitly addressed in the subsequent ANP analysis. The AHP-ANP result produced three levels of information with distinct meanings: *Si* shows each activity; Wi_ANP shows an activity's relative influence within the interacting system; and activity contribution (*Si* × *Wi*_ANP) shows each activity's effective contribution to regional sustainability as an interaction between its performance and its systemic importance, rather than mere mathematical multiplication. Integrating the activity *Si* with the interdependence-based activity weight (*Wi*_ANP) yielded a regional *CI* of 0.554, compared with 0.529 using AHP weights (Table 7). The activity with the highest *Si* (tourism, 0.695) received greater weight in ANP (0.252) than in AHP (0.155), so its positive contribution is better represented in *CI*; conversely, ponds received a lower ANP weight, reducing their negative contribution. Both *CI* values are classified as moderately sustainable (0.50–0.75) according to Kavanagh and Pitcher (2004). The regional status remains unchanged between the AHP and ANP approaches. The difference between *CI*_ANP and *CI*_AHP (+0.025) is numerically small; however, its significance arises from a structural shift in activity weights due to interdependence (*Wi*_AHP to *Wi*_ANP), rather than from measurement uncertainty or random variation. This makes the

difference methodologically significant despite its limited magnitude. The activity contribution (*Si* × *Wi*_ANP) exhibits a distinct pattern compared to *Si* and *Wi*_ANP individually. Fisheries (0.190), Ponds (0.189), and Tourism (0.175) contribute almost equally to the regional *CI*, despite notable differences in their *Si* and *Wi*_ANP values. This equivalence arises from the interaction between an activity's performance (*Si*) and its systemic importance (*Wi*_ANP). To illustrate, tourism achieves strong performance metrics despite limited systemic influence, whereas ponds display diminished performance alongside substantial systemic importance, resulting in virtually equivalent net contributions when combined. From a policy perspective, the aggregated contribution is particularly informative because it precisely captures the relative functional role of each activity within the regional sustainability framework. The primary management implication arises from the near-equal contribution pattern, which results from the interdependency structure captured by the ANP rather than the *CI* value alone. Because Ponds, Fisheries, and Tourism are interdependent through hub nodes, *CI*_AHP, which does not account for this interdependence, would suggest unilateral restrictions on Ponds. Under *Wi*_AHP, the contribution of Ponds (0.286) appears erroneously dominant. *CI*_ANP, which includes interdependency, instead recommends a synergistic co-management approach across all three activities. This recommendation stems from the capacity of ANP to capture inter-activity feedback and dependencies, distinguishing it from approaches driven strictly by higher quantitative *CI* outcomes. Indicator level reveals that three ecological indicators dominate: fisheries water quality (13.9%), pond water quality (13.4%), and tourism waste management (9.9%). Together, these account for 37% of *CI* despite comprising only 3 of 36 indicators. All three are also the best-performing field indicators (*Xi* = 0.850, 0.795, 0.800). Thus, the moderate sustainability classification rests primarily on favorable environmental conditions, not on social, economic, or governance strengths (Kesaulya *et al*., 2024; Oktorie *et al*., 2025; Romadhon *et al*., 2025; Zhang *et al*., 2024). This perspective is consistent with previous research indicating that a moderate overall sustainability score may mask substantial performance deficits across non-ecological dimensions (Joesidawati and Suwarsih, 2022; Munir and Misbah, 2025). Benchmarking these findings against existing coastal sustainability literature reveals notable instances of both methodological convergence and divergence. Convergence is evident in the repeated observation that environmental quality, particularly water quality, is a decisive attribute in coastal assessments, including waterfront sustainability in Pariaman, partial Indonesian Marine Health Index (IKLI) applications in Ambon and Baguala Bays, coastal tourism risk assessments on small islands, and coastal water quality studies in tourism-intensive marine áreas (Al-Qadami *et al*., 2025; Kesaulya *et al*., 2024; Kurniawan *et al*., 2023; Oktorie *et al*., 2025; Romadhon *et al*., 2025). However, divergence is also notable: while the present study identifies ecology as the principal source of strength, many earlier Rapfish/MDS-based studies in fisheries and coastal systems have found ecology, institutions, ethics, or socio-economic conditions to be the main sources of fragility, with overall systems often rated as less sustainable or only marginally sustainable (Jimenez *et al*., 2021; Parsaulian *et al*., 2024; Wulandari *et al*., 2026). This contrast suggests that Pariaman's multi-activity coastal system is not unusual in achieving only a moderate sustainability classification. Notwithstanding this trend, the profile remains distinctive as its performance is underpinned primarily by advantageous ecological states rather than progress in governance, institutional frameworks, market resilience, or social capacity, which are routinely emphasized as critical leverage domains in prior research (Engen *et al*., 2024; Jimenez *et al*., 2021; Munir and Misbah, 2025; Parsaulian *et al*., 2024; Wulandari *et al*., 2026). Methodologically, this comparison should be viewed as contextual

rather than confirmatory. By employing integrated AHP-ANP weighting, the present framework runs the risk of disproportionately amplifying the impact of a small subset of highly weighted, high-performing indicators. In contrast, many benchmark studies utilise Rapfish/MDS, IKLI/Ocean Health Index (OHI), coastal water quality indices, or Earth-observation-based indicators, each differing in attribute structure, scale, and weighting logic (Jimenez *et al*., 2021; Joesidawati and Suwarsih, 2022; Kurniawan *et al*., 2023; Valenti *et al*., 2018; Widyawati *et al*., 2024; Zhang *et al*., 2024). Therefore, the comparison with West Pasaman is informative but not strictly equivalent: its same-province score of 49.67 situates the present CI of 0.554 (55.4/100) within a comparable regional range, yet the West Pasaman result was primarily driven by dependence on fishing, environmental knowledge, harvest handling, and customary rules, reflecting a different sustainability structure from the ecology-led configuration observed here (Parsaulian *et al*., 2024). Furthermore, emerging scholarship underscores that coastal sustainability trajectories rely heavily on intersectoral dynamics among fisheries, aquaculture, and tourism. Such interactions mediate the redistribution of benefits and vulnerabilities throughout socio-ecological networks, driven explicitly by tourism pressure, aquaculture intensification, and climate change (Alsaleh and Wang, 2025; Kyvelou and Ierapetritis, 2020; Weatherdon *et al*., 2016). Fig. 7 confirms two things: the most striking shift among the three activities is in Pond weight when switching from AHP to ANP (panel a), and both weighting approaches still yield the same regional CI status of moderately sustainable despite different absolute values (panel b). The uniformity of this outcome confirms that the core findings of the study remain invariant to variations in the weighting approach employed. At the same time, differences at the activity level remain relevant for targeted intervention planning. Although both AHP and ANP classify the area as moderately sustainable, ANP's practical advantage lies in three interrelated points: the regional sustainability status is unchanged, the distribution of activity contributions changes substantially, and management intervention priorities differ between the two approaches. Although different methodologies may align on a region's overall status, they frequently exhibit divergent priorities. It is these variations in priority, rather than differences in status, that directly inform and drive practical decision-making. Beyond the methodological comparison, the CI 0.554 value itself carries substantive significance for the region. Sitting in the lower half of the moderately sustainable category (0.50-0.75) suggests considerable room for improvement before reaching highly sustainable status (0.75). Furthermore, the comparable contribution values observed across the three activities (0.190, 0.189, 0.175) demonstrate that improving regional sustainability gains cannot be achieved through sector-specific optimization alone. A simultaneous, cross-sectoral intervention strategy is essential, aligning directly with the network interdependencies captured by ANP. ANP's ability to systematically capture dependencies and feedback between criteria makes it a more capable instrument than AHP for reflecting real-world system complexity, more effectively bridging the gap between models and decision-making (Moslem *et al*., 2023; Sari *et al*., 2024). It loosens AHP's assumption of independence between criteria (Chen and Huang, 2023) and can be used to prioritize indicators and investigate relationships between criteria (Eriş *et al*., 2022). Sustainability assessments that consider spatial competition among economic activities, such as fisheries, aquaculture, and tourism, present a management challenge that is increasingly recognized in the applied MCDA literature (Zekić *et al*., 2025). The current study overcomes this limitation by proposing a composite index that accounts for performance metrics and systemic significance inherent to each activity.

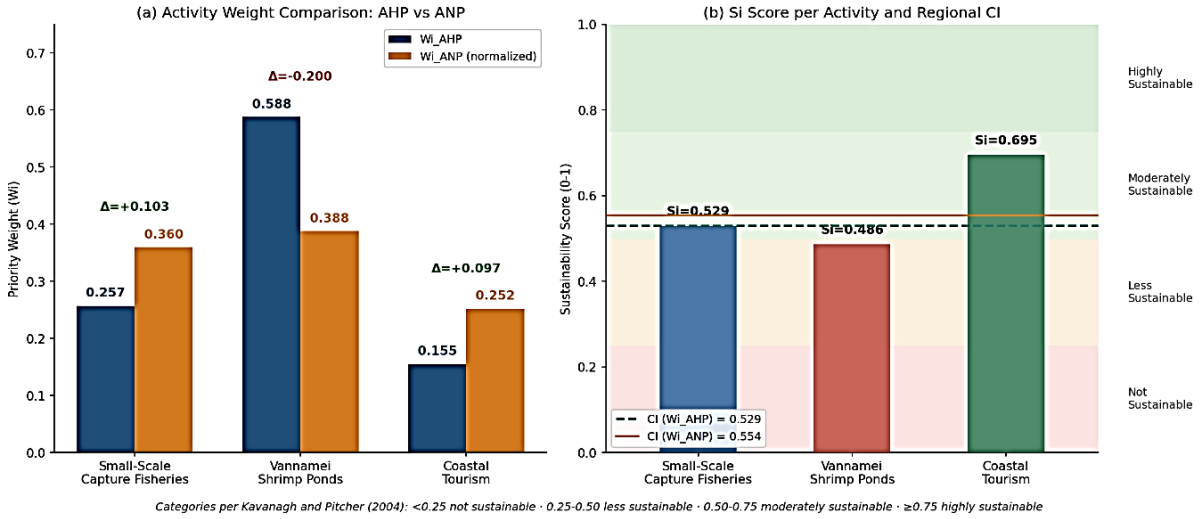

Fig. 7: Comparison of the weight of normalised *Wi*_AHP vs *Wi*_ANP activities (a) and the Pariaman coastal regional Sustainability composite Index (*CI*) (b). Both approaches produce the status: moderately sustainable (Kavanagh and Pitcher, 2004)

Table 8: Results of analysis of the sensitivity of the ANP weight to the regional *CI* and the order of priority of activities (variation ±10% and ±20%)

Varied Activities	Variasi	*Wi*_A1	*Wi*_A2	*Wi*_A3	*CI*	Weight sequence (*Wi*)	Order of contributions (*Si*×*Wi*)
Small-Scale Capture Fisheries	-20%	0.288	0.432	0.281	0.557	A2>A1>A3	A2>A3>A1*
Small-Scale Capture Fisheries	-10%	0.324	0.410	0.267	0.556	A2>A1>A3	A2>A3>A1*
Small-Scale Capture Fisheries	+10%	0.396	0.366	0.238	0.553	A1>A2>A3*	A1>A2>A3
Small-Scale Capture Fisheries	+20%	0.431	0.344	0.224	0.551	A1>A2>A3*	A1>A2>A3
Vannamei Shrimp Ponds	-20%	0.405	0.310	0.284	0.563	A1>A2>A3*	A1>A3>A2*
Vannamei Shrimp Ponds	-10%	0.382	0.349	0.268	0.558	A1>A2>A3*	A1>A3>A2*
Vannamei Shrimp Ponds	+10%	0.337	0.427	0.236	0.550	A2>A1>A3	A2>A1>A3*
Vannamei Shrimp Ponds	+20%	0.314	0.466	0.220	0.546	A2>A1>A3	A2>A1>A3*
Coastal Tourism	-20%	0.384	0.414	0.202	0.545	A2>A1>A3	A1>A2>A3
Coastal Tourism	-10%	0.372	0.401	0.227	0.549	A2>A1>A3	A1>A2>A3
Coastal Tourism	+10%	0.347	0.375	0.278	0.559	A2>A1>A3	A3>A1>A2*
Coastal Tourism	+20%	0.335	0.362	0.303	0.564	A2>A1>A3	A3>A1>A2*

A1 = Small-scale capture fisheries; A2 = Vannamei shrimp ponds; A3 = Coastal tourism. The sign (*) indicates the sequence changed from baseline (A2 > A1 > A3 for weight; A1 > A2 > A3 for Si×Wi's contribution). All 12 scenarios remained in the category of moderately sustainable (0.50–0.75).

Robustness results

Regional *CI* across all 12 tested scenarios ranged from 0.545 to 0.564 (baseline = 0.554), with a maximum deviation of only ±0.010 from baseline, remaining under 2% (approximately 1.8%) and consistently within the moderately sustainable class (Table 8). For individuals interested in the main conclusions, attention should be directed to the *CI* and Contribution Order (*Si*×*Wi*) columns, as they are vital for understanding the resilience of the outcomes. Additional fields are provided for detailed verification. The sustainability status classification (moderately sustainable, 0.50–0.75) did not change in any scenario, indicating the study's main conclusion that Pariaman's coastal area has a sufficiently sustainable status is robust against ANP weighting uncertainty of up to ±20%. However, the order of activity contribution to *CI* (*Si*×*Wi*_ANP) is much more sensitive than *CI* itself. At baseline, the margin between small-scale capture fisheries' contribution (0.190) and vannamei shrimp ponds' (0.189) is only 0.001,

much smaller than the margin in gross weight (*Wi*_ANP: 0.388 vs 0.360; margin 0.028). Consequently, rank reversals manifested across 8 out of 12 evaluated scenarios, including all instances where the vannamei shrimp pond weight was adjusted, including all instances where the vannamei shrimp pond weight. Such a small margin suggests that the two activities make comparable contributions to regional sustainability, precluding any inference of model error. Consequently, management strategies should avoid rigid prioritization between fisheries and shrimp ponds. This pattern aligns with the established finding in the composite index literature that robustness at the aggregate level and sensitivity at the level of constituent components are independent properties, each requiring separate evaluation (Choi, 2019; Wang *et al*., 2026). Far from indicating a structural flaw, the observed rank reversal underscores the model's sensitivity in differentiating between varying levels of spatial uncertainty. The composite index remains stable because it aggregates all three activities' contributions, making regional sustainability status independent of the specific order between activities; at the activity level, the contribution order is sensitive because it is empirically close to a tie, not because of methodological weakness. A genuinely robust framework should reveal these differences in sensitivity across levels, rather than uniformly reporting all results as 'stable' or 'unstable' regardless of level. While weighting uncertainty does not undermine the stability of regional sustainability status for long-term planning, the prioritization sequence between fisheries and aquaculture ponds requires flexibility. Given their near-equivalent contributions to the composite index, decisions must integrate qualitative and contextual drivers exogenous to the analytical framework. Sensitivity analysis shows the framework has two important characteristics: stable enough to produce a consistent region-level sustainability assessment, yet sensitive enough to detect small changes in relative contribution between activities, a combination that makes the framework suitable as a decision-support tool, able to distinguish genuinely stable findings from those still dependent on weight uncertainty.

Limitations

Internal validation relies on consistency ratios and the *CI*_ANP (0.554) versus *CI*_AHP (0.529) comparison. This demonstrates interpretable ranking shifts from incorporating interdependence. However, independent datasets, historical trends, or external benchmarks are unavailable, limiting external validation. Future empirical validation of the framework's regional composite index estimates against longitudinal monitoring datasets or independent sustainability metrics will be essential to corroborate model outputs and substantiate confidence beyond internal structural consistency. The AHP-ANP weights and *CI* values are specific to Pariaman's biophysical, socio-economic, and institutional context. To establish broader applicability, cross-site validation across analogous tropical coastal settings is required. Expanding the framework beyond three activities would increase ANP complexity combinatorially, raising the expert-elicitation burden and inconsistency risk. The framework is also inherently cross-sectional; it does not capture climate change, seasonal variability, or long-term land-use change that could alter activity interdependencies. Accounting for these shifting dynamics calls for systematic, iterative re-evaluation or the coupling of the framework with dynamic simulation models. The ANP network structure and weights reflect expert judgement rather than empirical interaction data. This introduces potential anchoring and framing biases that consistency ratios cannot detect. The 36-indicator set is also non-unique; alternative indicators could yield different weights and *CI* values. Because min-max normalization relies heavily on sample extrema, it exhibits limited robustness when encountering out-of-range data during prospective application. Consequently,

precise numerical reproduction requires the same expert panel, indicator set, and sample—an inherent constraint of expert-elicitation-based MCDA.

Policy implications

Priority setting extends beyond a simple numerical ranking. Given the marginal differences in activity contributions (Fisheries 0.190, Ponds 0.189, Tourism 0.175), governance frameworks should avoid depending solely on quantitative *Si* or *Wi*_ANP outputs, balancing them instead against underlying socioeconomic importance, ecological vulnerabilities, and stakeholder preferences. Targeted hub-node interventions outperform blanket restrictions. The correction of Ponds' weight (0.588 to 0.388) traces to three shared nodes: water quality, spatial conflicts, and zoning suitability. Interventions on pond effluent standards, spatial-use resolution, and zoning compliance would simultaneously benefit fisheries and tourism. A core strength of the framework lies in its ability to separate intrinsic sustainability dynamics from broader, indirect regional externalities. Ponds' low intrinsic score (*Si* = 0.486) reflects weak governance, yet the network reveals their wastewater degrades shared water quality and spatial nodes—a dynamic invisible to activity-level assessment. Policymakers should thus evaluate *Si* and *Wi*_ANP jointly. Decision-makers can apply the framework in four steps. First, use activity contributions (*Si* × *Wi*_ANP) to identify systemic weight. Second, trace hub nodes affected by each activity to locate cross-sectoral intervention points. Third, prioritize shared nodes for the greatest management return. Ultimately, the observed parity in activity contributions underscores the requirement for an integrated, multi-sectoral intervention framework; discrete, single-activity measures are insufficient to drive substantial shifts in the regional *CI*. The framework is a static, cross-sectional tool, not a forecasting model. Its supermatrix structure can support ex-ante scenario comparison using hypothetical indicator values, such as projected pond expansion. Nonetheless, achieving precise predictive capability requires integrating dynamic simulation models. The conclusion that hierarchical assessments tend to overestimate locally dominant, negatively interdependent sectors is broadly generalizable to other multi-activity resource conflicts. However, the specific numerical weights remain context-specific. Subsequent methodological extensions could integrate the framework with GIS for spatial deployment, employ, Bayesian networks for probabilistic modeling of hub-node interactions, or incorporate System Dynamics to simulate temporal feedback loops. Such integration pathways outline future development trajectories rather than existing framework capabilities.

CONCLUSION

This study developed and implemented an activity-based sustainability assessment framework integrating AHP and ANP for multi-activity coastal areas in Pariaman, West Sumatra. AHP calculated activity-level sustainability scores across four dimensions and 36 indicators. Coastal tourism scored highest (0.695), small-scale capture fisheries ranked middle (0.529), and vannamei shrimp ponds scored lowest (0.486). By structuring the system into five clusters comprising 14 indicator nodes and three activity nodes, the ANP network explicitly captured complex inter-activity dependencies. Regional *CI* calculated under both weighting schemes showed significant methodological implications. ANP corrected the overestimation of shrimp ponds from Wi_AHP = 0.588 to Wi_ANP = 0.388 (Δ = -0.200). Small-scale capture fisheries (+0.103) and coastal tourism (+0.097) strengthened after interdependence was incorporated. This finding demonstrates that reliance on AHP's foundational independence assumption generates contribution estimates unreflective of the complex interactions characteristic of multi-functional coastal environments. The ANP-weighted CI (0.554)

provides a more valid planning basis than the AHP-based *CI* (0.529). Both fall within the moderately sustainable category. Three hub nodes (coastal water quality, space utilization conflicts, and zoning suitability) provide empirical evidence of inter-activity dependency mechanisms directly relevant to integrated coastal zone management. Effective management of Pariaman's coastal area demands targeted interventions at three pivotal junctures—improving water quality, resolving spatial incompatibilities, and augmenting cross-sectoral governance. These leverage points affect the sustainability of more than one activity simultaneously. The main contribution of this research lies in the activity-based assessment framework itself, which is not merely the application of AHP-ANP to a new case, but an approach that explicitly models interdependencies between activities. It distinguishes between region-level stability and activity-level sensitivity. By offering a transferable decision-support architecture, the proposed framework facilitates systematic coastal sustainability assessments in comparable multi-activity areas. It is especially relevant for tropical regions with similar coastal utilization patterns. The theoretical contribution demonstrates that hierarchical assessment systematically overestimates locally dominant activities that are negatively interdependent with others. An interdependence-aware network layer corrects this overestimation traceably by identifying hub nodes. The practical contribution translates this correction into targeted, hub-node-based management guidance. This replaces the blanket single-activity restrictions implied by purely hierarchical assessments. The underlying two-layer logic is not limited to coastal systems. By synthesizing an intrinsic hierarchical evaluation with a network-based layer that accounts for competitive interactions over shared resources, the approach establishes a robust logic transferable to broader natural resource management contexts. Examples include river-basin water allocation among agricultural, industrial, and municipal users, or multi-use forest landscapes where logging, agriculture, and conservation zones interact through shared hydrological and habitat connectivity. Subsequent studies might expand the utility of the framework by incorporating evolving environmental conditions, broader ecosystem service portfolios, increased stakeholder participation in indicator curation, and advanced analytical approaches including System Dynamics, Bayesian networks, or spatially explicit modelling. These enhancements would strengthen both the predictive capability and the applicability of the framework to a wider range of coastal and non-coastal resource management settings.

AUTHOR CONTRIBUTIONS

Desrizal, contributed to the conceptualization, methodology, software, validation and writing the original draft. B. Widigdo, assisted with the methodology, validation, formal analysis and resources. G. Yulianto, contributed to writing, reviewing and visualization. F. Kurniawan, assisted with writing, reviewing and editing. Sulistiono, the corresponding author, supervised the project, writing, reviewing and editing.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been completely observed by the authors.

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POSITIVE AI STATEMENT

During the preparation of this work, the author(s) have used Artificial Intelligence (AI) tools, Claude (Anthropic), ChatGPT (OpenAI) and Grammarly, to assist in data compilation and verification, as well as refinement of the manuscript language. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

ABBREVIATIONS

%	Percent
A1, A2, A3	Activity code (Table 7): A1 = Small-scale capture fisheries, A2 = Vannamei shrimp ponds, A3 = Coastal tourism
AHP	Analytic hierarchy process
ANP	Analytic network process
BPS	Central bureau of statistics (Badan Pusat Statistik), Indonesia
CI	Composite sustainability index
CR	Consistency ratio
E, S, K, G	Sustainability dimension code: Ecology, Social, Economy, Governance
FAO	Food and agriculture organization
GIS	Geographic information system
GT	Gross tonnage
IKLI	Indonesian marine health index (Indeks Kesehatan Laut Indonesia)
MCDA	Multi-criteria decision analysis
MDS	Multidimensional scaling
NGO	Non-governmental organization
OAT	One-at-a-time
OECD	Organisation for economic co-operation and development
OHI	Ocean Health Index
Si	Sustainability score per activity
Wi	Weight/priority vector
WQI	Water quality index

REFERENCES

Akram, H.; Hussain, S.; Mazumdar, P.; Chua, K. O.; Butt, T. E.; Harikrishna, J. A., (2023). Mangrove health: A review of functions, threats, and challenges associated with mangrove management practices. Forests. 14(9): 1-38 **(38 pages).**

Al-Qadami, E.H.H.; Razi, M.A.M.; Shah, S.M.H.; Mokhtar, A.; Mahamud, M.; Jamal, M.H.; Ismail, Z.A., (2025). Marine water and sediment quality assessment of mainland Kedah and Langkawi Island shorelines: A case study. IOP Conference Series: Earth Environ. Sci., 1453(1): 1-12 **(12 pages).**

Alsaleh, M.; Wang, X., (2025). Aquaculture growth and coastal tourism development in the context of sustainable blue economy. Sustainable Dev., 33(2): 2030-2046 **(17 pages).**

Ariadi, H.; Musa, M.; Mahmudi, M.; Hertika, A. M. S., (2025). The waste load and carrying capacity on intensive shrimp farming: A mini review. Ecol. Eng. Environ. Technol., 26(4): 323–333 **(11 pages).**

Arifanti, V.B.; Novita, N.; Subarno; Tosiani, A., (2021). Mangrove deforestation and CO_2 emissions in Indonesia. IOP Conference Series: Earth Environ. Sci., 874(1): 1-10 **(10 pages).**

Berkes, F., (2017). Environmental governance for the anthropocene? Social-ecological systems, resilience, and collaborative learning. Sustainability. 9(7): 1232 **(1 page).**

BPS Padang Pariaman Regency, (2025). Padang Pariaman Regency in figures 2025. BPS-Statistics Padang Pariaman Regency, 26: 1–749 **(749 pages).**

BPS Pariaman City, (2025). Pariaman City in figures 2025. BPS-Statistics Pariaman Municipality, 22: 1–564 **(564 pages).**

Boustead, R.; Bhatta, S., (2021). Assessment of the social impacts of community based tourism. Z. Tourismuswiss. 13(2): 268-302 **(35 pages).**

Boyd, C.E.; D'Abramo, L.R.; Glencross, B.D.; Huyben, D.C.; Juarez, L.M.; Lockwood, G.S.; McNevin, A.A.; Tacon, A.G.J.; Teletchea, F.; Tomasso, J.R.; Tucker, C.S.; Valenti, W.C., (2020). Achieving sustainable aquaculture: Historical and current perspectives and future needs and challenges. J. World Aquacult. Soc., 51(3): 578-633 **(56 pages).**

Boyd, C.E.; Davis, R.P.; McNevin, A.A., (2022). Perspectives on the mangrove conundrum, land use, and benefits of yield intensification in farmed shrimp production: A review. J. World Aquacult. Soc., 53(1): 8-46 **(39 pages).**

Cabrera, J.S.; Lee, H.S., (2022). Coastal zone environment integrity assessment for sustainable management: Part 1. Development of adaptive expert-driven coastal zone health index framework. J. Mar. Sci. Eng., 10(9): 1-19 **(19 pages).**

Chen, C.Y.; Huang, J.J., (2023). Integrating dynamic Bayesian networks and analytic hierarchy process for time-dependent multi-criteria decision-making. Mathematics. 11(10): 1-12 **(12 pages).**

Chen, L.; Ren, J., (2017). Multi-attribute sustainability evaluation of alternative aviation fuels based on fuzzy ANP and fuzzy grey relational analysis. J. Air Transp. Manage., 68: 176–186 **(11 pages).**

Chuang, Y.H.; Yu, R.F.; Chen, W.Y.; Chen, H.W.; Su, Y.T., (2018). Sustainable planning for a coastal wetland system with an integrated ANP and DPSIR model for conflict resolution. Wetlands Ecol. Manage., 26(6): 1-12 **(12 pages).**

Daimi, S.; Rebai, S., (2023). Sustainability performance assessment of Tunisian public transport companies: AHP and ANP approaches. Socio-Econ. Plann. Sci., 89: 101680 **(1 page).**

Darko, A.; Chan, A. P. C.; Ameyaw, E. E.; Owusu, E. K.; Pärn, E.; Edwards, D. J., (2019). Review of application of analytic hierarchy process (AHP) in construction. Int. J. Constr. Manage., 19(5): 436–452 **(17 pages).**

de Lacerda, L. D.; Ward, R. D.; Godoy, M. D. P.; Meireles, A. J. de A.; Borges, R.; Ferreira, A. C., (2021). 20-years cumulative impact from shrimp farming on mangroves of northeast brazil. **Front. For. Glob. Change.,** 653096 (4): 1-17 **(17 pages).**

Desrizal, D.; Widigdo, B.; Yulianto, G.; Kurniawan, F.; Sulistiono, S., (2025). Legal status of aquaculture ponds and coastal compliance in Padang Pariaman. IOP Conference Series.: Earth Environ. Sci., 1543(1): 1-13 **(13 pages).**

Engen, S.; Hausner, V.H.; Mikkelsen, E.; Gundersen, H.; Christie, H.; Falk-Andersson, J.; Halpern, B.S.; Fauchald, P., (2024). Co-creating coastal sustainability goals and indicators. Sustainable Sci., 19(4): 1327-1343 **(17 pages).**

Eriş, M.B.; Sezer, E.D.G.; Ocak.; Z., (2023). Prioritization of the factors affecting the performance of clinical laboratories using the AHP and ANP techniques. Netw. Model. Anal. Health Inform. Bioinforma. 12 (1): 5 **(1 page).**

FAO, (2022). The state of world fisheries and aquaculture 2022. FAO, Rome, Italy. 1-266 **(266 pages).**

Firdaus, M.; Sulistiono; Widigdo, B., (2021). Brackishwater pond development: present status and problems in the Padang Pariaman Regency of West Sumatra, Indonesia. E3S Web Conference. 05009 (322):1-12 **(12 pages).**

Folke, C.; Biggs, R.; Norström, A.V.; Reyers, B.; Rockström, J., (2016). Social-ecological resilience and biosphere-based sustainability science. Ecol. Soc., 21(3): 41 **(1 page).**

Goldberg, L.; Lagomasino, D.; Thomas, N.; Fatoyinbo, T., (2020). Global declines in human-driven mangrove loss. Global Change Biol., 26(10): 5844-5855 **(12 pages).**

Gonzalez-Urango, H.; Mu, E.; Ujwary-Gil, A.; Florek-Paszkowska, A., (2023). Analytic network process in economics, finance and management: Contingency factors, current trends and further research. Expert Syst. Appl., 121415 (237): 1-13 **(13 pages).**

Hossain, M.S.; Gain, A.K.; Rogers, K.G., (2020). Sustainable coastal social-ecological systems: How do we define "coastal"?. Int. J. Sustainable Dev. World Ecol., 27(7): 577-582 **(6 pages).**

Huang, J. J.; Chen, C. Y., (2024a). Resource allocation of cooperative alternatives using the analytic hierarchy process and analytic network process with shapley values. Algorithms. 17(4): 1-15 **(15 pages).**

Huang, J. J.; Chen, C. Y., (2024b). Using markov random field and analytic hierarchy process to account for Interdependent criteria. Algorithms, 17(1): 1-13 **(13 pages).**

Iber, B. T.; Kasan, N. A., (2021). Recent advances in Shrimp aquaculture wastewater management. Heliyon. 7(11): 1-9 **(9 pages).**

Il Choi, H., (2019). Assessment of aggregation frameworks for composite indicators in measuring flood vulnerability to climate change. Sci. Rep., 19371(9): **(1 page).**

Jimenez, É.A.; Gonzalez, J.G.; Amaral, M.T.; Lucena Frédou, F., (2021). Sustainability indicators for the integrated assessment of coastal small-scale fisheries in the Brazilian Amazon. Ecol. Econ., 181: 1-14 **(14 pages).**

Joesidawati, M.I.; Suwarsih, S., (2022). Measurement of Indonesian Marine Health Index to assess the health of the coastal ecosystem of Tuban, East Java. IOP Conference Series: Earth Environ. Sci., 1036(1): 1-13 **(13 pages).**

Jorge-García, D.; Estruch-Guitart, V., (2022). Comparative analysis between AHP and ANP in prioritization of ecosystem services - A case study in a rice field area raised in the Guadalquivir marshes (Spain). Ecol. Inform., 70 (101739): 1-11 **(11 pages).**

Kadoić, N.; Ređep, N.B.; Divjak, B., (2017). Decision making with the analytic network process. Int. J. Anal. Hierarchy Process:1-7 (**7 pages).**

Kakkar, S.; Upadhyay, P., (2025). Structural challenges and sustainability deficits in rural tourism: A conceptual review of long-term economic and environmental impacts on local communities. Adv. Int. J. Res., 6(6): 1-5 **(5 pages).**

Kavanagh, P.; Pitcher, T.J., (2004). Implementing Microsoft Excel software for Rapfish: A technique for the rapid appraisal of fisheries status. Fish. Cent. Res. Rep., 12(2): 1-80 **(80 pages).**

Kesaulya, I.; Haumahu, S.; Nikijuluw, V.P.H.; Djakiman, C., (2024). A partial analysis of ocean health index based on clean waters and biodiversity goals in Ambon and Baguala bays, Maluku. Depik, 13(1): 64-71 **(8 pages).**

Ketaren, D. G. K.; Radjawane, I. M.; Latief, H.; Sidik, F.; Trenggono, S. W.; Diantara, S. D.; Setyawidati, N. A. R.; Akbar, M. I.; Raja, J. A. L.; Farkhan, M. A.; Kasim, K.; Maharani, S., (2026). Impacts of mangrove land use change on carbon stocks in coastal ecosystems. Global J. Environ. Sci. Manag.. 12(3): 1041-1060 **(20 pages).**

Kheybari, S.; Rezaie, F.M.; Farazmand, H., (2020). Analytic network process: An overview of applications. Appl. Math. Comput., 124780 (367): **(1 pages).**

Kyvelou, S.S.I.; Ierapetritis, D.G., (2020). Fisheries sustainability through soft multi-use maritime spatial planning and local development co-management: Potentials and challenges in Greece. Sustainability. 12(5): 1-26 **(26 pages).**

Kurniawan, F.; Adrianto, L.; Bengen, D.G.; Prasetyo, L.B., (2023). Hypothetical effects assessment of tourism on coastal water quality in the Marine Tourism Park of the Gili Matra Islands, Indonesia. Environ. Dev. Sustainable. 25(8): 7959-7985 **(27 pages).**

Lin, G.; Zhang, Q.; Zhang, Y.; Shen, C.; Xu, H.; Wang, S., (2024). Performance assessment of public transport networks: An AHP-ANP approach. Heliyon. 10(22): 1-11 **(11 pages).**

McSherry, M.; Davis, R.P.; Andradi-Brown, D.A.; Ahmadia, G.N.; Van Kempen, M.; Wingard Brian, S., (2023). Integrated mangrove aquaculture: The sustainable choice for mangroves and aquaculture?. Front. For. Global Change., 1094306(6): 01-08 **(8 pages).**

Moslem, S.; Solieman, H.; Oubahman, L.; Duleba, S.; Senapati, T.; Pilla, F., (2023). Assessing public transport supply quality: A comparative analysis of analytical network process and analytical hierarchy process. J. Soft Comput. Decis. Anal., 1(1): 124-138 **(15 pages).**

Munir, M.; Misbah, A., (2025). Sustainability analysis of skipjack tuna catch based on multidimensional scaling (MDS) in the coastal area of Pasuruan Regency. AGROMIX, 16(1): 155-167 **(13 pages).**

Nardo, M.; Saisana, M.; Saltelli, A.; Tarantola, S.; Hoffmann, A.; Giovannini, E., (2005). Handbook on constructing composite indicators: Methodology and user guide. OECD Statistics Working Papers, OECD Publishing, Paris, France: 1-109 **(109 pages).**

Navarro, I.J.; Martí, J.V.; Yepes, V., (2022). Analytic network process-based sustainability life cycle assessment of concrete bridges in coastal regions. Sustainability. 14(17): 1-16 **(16 pages).**

Newton, A.; Icely, J.; Cristina, S.; Perillo, G.M.E.; Turner, R.E.; Ashan, D.; Cragg, S.; Luo, Y.; Tu, C.; Li, Y.; Zhang, H.; Ramesh, R.; Forbes, D.L.; Solidoro, C.; Béjaoui, B.; Gao, S.; Pastres, R.; Kelsey, H.; Taillie, D.; Kuenzer, C., (2020). Anthropogenic, direct pressures on coastal wetlands. Front. Ecol. Evol., 8: 144 **(29 pages).**

Ofori, S.A.; Kodikara, S.K.A.; Jayatissa, L.P.; Madarasinghe, S.K.; Nijamdeen, T.W.G.F.M.; Dahdouh-Guebas, F., (2023). What is the ecological footprint of aquaculture after 5 decades of competition between mangrove conservation and shrimp farm development?. Aquat. Conserv. Mar. Freshw. Ecosyst., 33(1): 15-28 **(14 pages).**

Oktorie, O.; Dewata, I.; Barlian, E.; Hermon, D.; Putra, A., (2025). Assessing the sustainability of lagoon-based environmental waterfront in the coastal zone of Pariaman City, Indonesia. Geogr. Technol., 20(2): 134-149 **(16 pages).**

Ottinger, M.; Bachofer, F.; Huth, J.; Kuenzer, C., (2022). Mapping aquaculture ponds for the coastal zone of Asia with Sentinel-1 and Sentinel-2 time series. Remote Sens., 14(153): 1-25 **(25 pages).**

Parsaulian, B.; *et al*., (2024). Re-thinking Indonesian fisheries policy: empowerment of a hidden asset for sustainable fisheries in West Pasaman District, West Sumatra, Indonesia. Int. J. Environ. Impacts. 7(1): 1-16 **(16 pages).**

Pourebrahim, S.; Hadipour, M.; Mokhtar, M.B.; Hj Mohamed, M.I., (2010). Analytic network process for criteria selection in sustainable coastal land use planning. Ocean Coast. Manage., 53(9): 544-551 **(8 pages).**

Rahmat, Y.N.; Neilson, J., (2023). The ebb and flow of capital in Indonesian coastal production systems. Singapore J. Trop. Geogr., 44(2): 300-321 **(22 pages).**

Reddy, G.P.O., (2018). Spatial data management, analysis, and modeling in gis: principles and applications. Springer international publishing, Cham, Switzerland: 127-142 **(16 pages).**

Richards, D.R.; Friess, D.A., (2016). Rates and drivers of mangrove deforestation in Southeast Asia, 2000-2012. Proc. Natl. Acad. Sci. U.S.A., 113(2): 344-349 **(6 pages).**

Rizky, P. N.; Halim, A. M.; Nisa, A. C.; Prama, E. A.; Ulfauza, Oktahimawan, M. K., (2025). Spatial variability of water and sediment quality in pond outlet: Implications for coastal ecosystems in mangrove areas, Pasuruan, East Java. HAYATI J. Biosci., 32(5): 1313–1323 **(11 pages).**

Romadhon, A.; Rini, D.A.S.; Hilyana, S., (2025). Ecological risk assessment for sustainable tourism on Saobi Island, Indonesia. Asian J. Ethnobiol., 8(2): 291-300 **(10 pages).**

Saaty, T. L., (2004). Fundamentals of the analytic network process — Dependence and feedback in decision-making with a single network. J. Syst. Sci. Syst. Eng., 13(2): 129–157 **(29 pages).**

Saaty, T.L., (2006). An analytic network process model for financial-crisis forecasting. Int. J. Forecast., 22(1): 1-15 **(15 pages).**

Saaty, T.L., (2008). Decision making with the analytic hierarchy process. Int. J. Services Sci., 1(1): 83-98 **(17 pages).**

Saaty, T.L., (2014). Analytic hierarchy process. In: Balakrishnan, N.; Colton, T.; Everitt, B.; Piegorsch, W.; Ruggeri, F.; Teugels, J.L. (Eds.), Wiley StatsRef: Statistics Reference Online. John Wiley & Sons, Hoboken, NJ, USA **(15 pages).**

Saaty, T.L., (1996). Decision Making with dependence and feedback: The Analytic Network Process. RWS Publications, Pittsburgh, PA, USA: 1-2 **(2 pages).**

Saaty, T.L.; Vargas, L.G., (2006). Decision Making with the Analytic Network Process: Economic, Political, Social and Technological Applications with Benefits, Opportunities, Costs and Risks. Springer, New York, NY, USA: 1-283 **(283 pages).**

Saaty, T.L.; Vargas, L.G., (2012). Models, Methods, Concepts and Applications of the Analytic Hierarchy Process, Second Edition. Springer, New York, NY, USA: 1-342 **(342 pages).**

Sánchez-Garrido, A.J.; Navarro, I.J.; García, J.; Yepes, V., (2022). An adaptive ANP and ELECTRE IS-based MCDM model using quantitative variables. Mathematics. 10(12): 1-24 **(24 pages).**

Sari, I.; Ichsan, M.; White, A.; Raup, S.A.; Wisudo, S.H., (2021). Monitoring small-scale fisheries catches in Indonesia through a fishing logbook system: Challenges and strategies. Mar. Policy. 134: 104770: 1-7 **(7 pages).**

Sari, R.; Kurniastuti, I.; Sulistiyani, E., (2024). Comparative analysis of prioritization model between AHP and ANP for project portfolio management SI/IT Surabaya City Government. Appl. Technol. Comput. Sci. J., 6(2): 88-95 **(8 pages).**

Silalahi, H. T.; Basyuni, M.; Aritonang, E. Y.; Slamet, B.; Hartini, K. S.; Wee, A. K. S., (2024). Management of mangrove landscape and ecosystem for ecotourism. Global J. Environ. Sci. Manage., 10(4): 1977–1992 **(16 pages).**

Srđević, B.; Srđević, Z., (2024). Multi-model assessing and visualizing consistency and compatibility of experts in group decision-making. Mathematics. 12(11): 1-21 **(21 pages).**

Stacey, N.; Gibson, E.; Loneragan, N.R.; Warren, C.; Wiryawan, B.; Adhuri, D.S.; Steenbergen, D.J.; Fitriana, R., (2021). Developing sustainable small-scale fisheries livelihoods in Indonesia: Trends, enabling and constraining factors, and future opportunities. Mar. Policy. 132: 1-12 **(12 pages).**

Stanford, R.J.; Wiryawan, B.; Bengen, D.G.; Febriamansyah, R.; Haluan, J., (2014). Improving livelihoods in fishing communities of West Sumatra: More than just boats and machines. Mar. Policy. 45: 16-25 **(10 pages).**

Tian, W.; Bai, J.; Sun, H.; Zhao, Y., (2013). Application of the analytic hierarchy process to a sustainability assessment of coastal beach exploitation: A case study of the wind power projects on the coastal beaches of Yancheng, China. J. Environ. Manage., 115: 251-256 **(6 pages).**

Tuyen, V.V., (2024). Prioritization of coastal environmental risks under climate change in Quang Ngai, Vietnam: An integrated analytic network process—Risk score approach. Acadlore Trans. Geoscience. 3(4): 237-251 **(15 pages).**

Valenti, W.C.; Kimpara, J.M.; Preto, B. de L.; Moraes-Valenti, P., (2018). Indicators of sustainability to assess aquaculture systems. Ecol. Indic., 88: 402-413 **(11 pages).**

Wang, P.; O'Brien, F.; Son, J.Y.; Heo, S.; Bell, M.L.; Dubrow, R.; Chen, K., (2026). An updated modeling framework and sensitivity analysis of methodology for the climate health vulnerability index. Nat. Commun., 17: 1417 **(1 page).**

Weatherdon, L.V.; Magnan, A.K.; Rogers, A.D.; Sumaila, U.R.; Cheung, W.W.L., (2016). Observed and projected impacts of climate change on marine fisheries, aquaculture, coastal tourism, and human health: An update. Front. Mar. Sci., 3: 48 **(21 pages).**

Widigdo, B.; Ilman, M.; Santoso, N.; Sulistiono; Kusmana, C.; Krisanti, M., (2024). Performance of integrated mangrove-aquaculture (IMA) in District of Sidoarjo, East Java Indonesia. Bio-Web Conference. 92: 01022: 1-9 **(9 pages).**

Widyawati, K.; Kusmana, C.; Pertiwi, S.; Sulistyantara, B., (2024). Rapid assessment of the sustainability status of tourism area management through MDS-Rapfish R in Situ Rawa Kalong, Depok City, West Java, Indonesia. Int. J. Sustain. Dev. Plan., 19(6): 2059-2068 **(10 pages).**

Więckowski, J.; Sałabun, W., (2023). Sensitivity analysis approaches in multi-criteria decision analysis: A systematic review. Appl. Soft Comput., 148: 110915: 1-19 **(19 pages).**

Wulandari, U.; Purwanti, P.; Setyohadi, D.; Abidin, Z., (2026). Multidimensional rapfish analysis of Danish seine fisheries in Brondong, Indonesia: Ecological, economic, social, technological, and ethical perspectives. Fish. Aquat. Sci., 29(3): 152-165 **(14 pages).**

Yuliana, E.; Nurilmala, M., Rahadiati, A.; Farida, I.; Kurniawati, H.; Agustina, S.; Difah, D. A.; Pertiwi, P. R.; Wicaksana, B. E.; Ramilo, R. V.; Djatmiko, W. A., (2026a). Provisioning ecosystem services through the sustainable management of fish resources extracted by small-scale fishers. Global J. Environ. Sci. Manage., 12(3): 1311-1332 **(21 pages).**

Yuliana, E.; Winata, A.; Setijorini, L. E.; Yani, D. E.; Fathani, M. H.; Djatmiko, W. A., (2026b). Biodiversity-oriented criteria for measuring the effectiveness of mangrove ecosystem rehabilitation success. Global J. Environ. Sci. Manage., 12(4): 1-20 **(20 pages).**

Zamzami, L.; Azwar, Darman Moenir, H., (2023). Enhancing social resilience and addressing economic uncertainty in small-scale fishing households along the west coast of West Sumatra. Bio-Web of Conference. 74: 1-10 **(10 pages).**

Zekić, A.; Gundić, A.; Grbić, L.; Vukić, M., (2025). The application of multi-criteria analysis to coastal zone management decision-making. Sustainability. 17(13): 6194: 1-17 **(17 pages).**

Zhang, L.; Zuo, J.; Chen, B.; Liao, J.; Yan, M.; Bai, L.; Sutrisno, D.; Hashim, M.; Mamun, M.M.A. Al., (2024). Improved indicators for the integrated assessment of coastal sustainable development based on Earth observation data. Int. J. Digit. Earth. 17(1): 1-21 **(21 pages).**

Ziemba, P., (2019). Inter-criteria dependencies-based decision support in the sustainable wind energy management. Energies. 12(4): 749: 1-29 **(29 pages).**

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